The Intelligent Ground Vehicle Competition: Intelligent Teams Creating Intelligent Ground Vehicles

Bernard L. Theisen
U.S. Army Tank Automotive Research, Development and Engineering Center

Gerald R. Lane
Applied Research Associates, Inc.

ABSTRACT

The Intelligent Ground Vehicle Competition (IGVC) has challenged university student teams to develop, test, and compete with their intelligent vehicles for over 13 years. The competition was initially founded and still sponsored by the Association for Unmanned Vehicle Systems International (AUVSI). The IGVC has been hosted by Oakland University (OU) and U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) since its beginning and supported by the Society of Automotive Engineers (SAE) for the past 11 years. The contest is open to all engineering schools and requires student teams to design and build autonomous vehicles of golf cart or smaller size that compete on two challenging courses on an open field. The contest also includes a design competition, run in conjunction with the performance events, in which all teams are required to participate.

INTRODUCTION

The Intelligent Ground Vehicle Competition (IGVC) is one of three, unmanned systems, student competitions that were founded by the Association for Unmanned Vehicle Systems International (AUVSI) in the 1990s. The IGVC is a multidisciplinary exercise in product realization that challenges college engineering student teams to integrate advanced control theory, machine vision, vehicular electronics, and mobile platform fundamentals to design and build an unmanned system. Both U.S. and international teams focus on developing a suite of dual-use technologies to equip ground vehicles of the future with intelligent driving capabilities. Over the past 13 years, the competition has challenged undergraduate, graduate and Ph.D. students with real world applications in intelligent transportation systems, the military and manufacturing automation. To date, teams from over 50 universities and colleges have participated. This paper describes some of the applications of the technologies required by this competition and discusses the educational benefits. The

primary goal of the IGVC is to advance engineering education in intelligent vehicles and related technologies. The employment and professional networking opportunities created for students and industrial sponsors through a series of technical events over the three-day competition are highlighted. Finally, an assessment of the competition based on participant feedback is presented.

MAIN SECTION

The objective of the competition is to challenge students to think creatively as a team about the evolving technologies of vehicle electronics, controls, sensors, computer science, robotics, and systems integration throughout the design, fabrication, and field testing of autonomous intelligent mobile robots. The competition has been highly praised by faculty advisors as an excellent multidisciplinary design experience for student teams, and a number of engineering schools give credit in senior design courses for student participation.

Figure 1: Virginia Polytechnic Institute and State University – Gemini, 2005 IGVC Grand Award Winner.

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Intelligent vehicles have many areas of relevance for both civilian and military applications. Vehicle intelligence can be applied to civilian applications in automating future highways or enhancing the safety of individual automobiles and trucks. For the Department of Defense (DoD), intelligent vehicles have the potential to greatly increase the effectiveness of the Army's Future Force by removing Soldiers from high risk tasks, as well as a desirable high payoff potential in multiplying combat assets, thus increasing unit combat power. Technology objectives identified in both DoD and Department of Transportation (DoT) programs have been used to structure the IGVC.

Figure 2: University of Wisconsin - Madison – Whitespace, tweaking on the Practice Course.

Based on the IGVC technical objectives, a number of co-sponsors have joined to help, fund, and promote the IGVC. Present and past co-sponsors include the AUVSI, Oakland University, TARDEC, SAE, Fanuc Robotics, the Automated Highway Systems (AHS) Consortium, General Dynamics Land Systems (GDLS), the United Defense Limited Partnership (UDLP), the DoT, Ford Motor Co., General Motors (GM), SAIC, Motorola, CSI Wireless, the Defense Advanced Research Projects Agency (DARPA), the DoD Joint Robotics Program (JRP) and the U.S. Air Force Research Laboratory (AFRL). A common interest of all these organizations is intelligent vehicles and their supporting technologies. The IGVC challenges the students to design, develop, build, demonstrate, report, and present integrated systems with intelligent technologies which can lane-follow, avoid obstacles, operate without human intervention on slopes, natural environments, and simulated roads, autonomously navigate with global positioning systems (GPS) and to perform leader-follower applications. The civilian aspect of this dual use technology is underpinned by the automotive applications.

The IGVC has three components: a mandatory Design Competition, the Autonomous Challenge, and the Navigation Challenge. The total award money amount of all three competitions is currently over $25,000. In the

Design Competition, judges determine winners based on written and oral presentations and on examination of the vehicles. While in the Autonomous Challenge, the robotic vehicles negotiate an outdoor obstacle course approximately 200 meters long. The Navigation Challenge requires vehicles to travel from a starting point to a number of target destinations using global positioning system (GPS) waypoints.

THE COMPETITION EVENTS

The Autonomous Challenge event requires a fully autonomous unmanned ground robotic vehicle to negotiate around an outdoor obstacle course under a prescribed time while staying within the five mile-per-hour speed limit and avoiding obstacles on the track. The course consists of a 500 foot long, ten foot wide lane with white lane markings on grass. White five-gallon buckets, orange construction barrels, and simulated potholes serve as obstacles spaced along the lane. There are ramps, sections of simulated asphalt and simulated sand pits that have to be negotiated. The vehicles are judged based on their ability to perceive the course environment and avoid obstacles. A human operator cannot remotely control vehicles during competition. All computational power, sensors, and control equipment must be carried on board the vehicle to achieve autonomous driving with computer vision and obstacle detection technologies. Judges will rank the entries that complete the course based on shortest adjusted time taken. In the event that a vehicle does not finish the course, the judges will rank the entry based on longest adjusted distance traveled. Adjusted time and distance are the net scores given by judges after taking penalties, incurred from obstacle collisions, pot hole hits, and boundary crossings, into consideration. The vehicle that travels the farthest on the course, or completes the course in the shortest time wins; award money for this event totals $6,000.

Figure 3: Trinity College - ALVIN VI, on an Autonomous Challenge run.

The Design Competition is a mandatory part of the IGVC. Participation in the two performance challenges is optional, however it is expected that all teams will

design and equip their vehicles to compete in the Autonomous Challenge, the Navigation Challenge, and design reports will be judged accordingly. Failure to fully qualify for the performance events will result in only nominal prize awards in the Design Competition. Although the ability of the vehicles to negotiate the competition course is the ultimate measure of product quality, officials are also interested in the design process that engineering teams follow to produce their vehicles. Design judging is performed by a panel of experienced engineering judges and is conducted separate from and without regard to the vehicle's performance on the Autonomous and Navigation Challenges. Judging is based on a 15 page written report, a 10 minute oral presentation, and an examination of the vehicle. In the interest of engineering discipline, design reports that are received after the deadline date are penalized in the judging, as are oral presentations running longer than the specified time. The award money for this event totals $3,000.

Figure 4: University of Central Florida – RDB3K, during the vehicle inspection of the Design Competition.

The Navigation Challenge event is a practice that is thousands of years old. Procedures have continuously improved from line-of-sight to moss on trees to dead reckoning to celestial observation to the use of global positioning systems (GPS). The challenge in this event is for a vehicle to autonomously travel from a starting point to a number of target destinations (waypoints or landmarks) and return to home base, provided only a map showing the coordinates of those targets. Coordinates of the targets are given in latitude and longitude as well as in meters on an x-y grid. The vehicle thus needs to incorporate GPS technology with computer vision, obstacle detection and avoidance to find and reach the targets. The vehicle visiting the most waypoints in a given (or the shortest) time wins; award money for this event totals $3,000.

THE COMPETITION RULES (IN BRIEF)

Vehicles must be entirely autonomous and cannot be controlled by a human operator during competition. All computational power, sensing, and control equipment must be carried on board the vehicle; except there must be both a manual and wireless remote emergency stop capability meeting strict specifications.

Chassis can be built from scratch or commercially bought (all-terrain vehicle, golf cart, lawn tractor, electric wheel chair, etc.). Overall dimensions cannot exceed 2.7 meters in length, 1.5 meters in width and 2 meters in height. Propulsion must be by direct mechanical contact with the ground, and power must be supplied either electrically or by combustible fuel. Vehicles must have a maximum speed of 8 kph for safety and must carry a 9 kilogram load during competition.

The Autonomous Challenge course is laid out on grass with sections of simulated asphalt, a simulated sand pit, and an artificial incline with a 15% grade. Lane markers (lines) are painted white and are 3 meters apart. The turning radius is not less than 2.4 meters. One section has alternating dashed lines, while another section has no lane markers at all for 6 meters. Obstacles consist of 19 liter white buckets or full-size orange construction barrels. White-painted simulated and actual potholes need to be avoided. Traffic tickets or run terminations are made by the judges for various infringements on the course (crossing the lane markers or potholes, striking an obstacle, etc.). The course layout is changed every year and obstacles are moved between runs.

Figure 5: Hosei University – amigo 2005, reprogramming on the Practice Course.

The Navigation Challenge course is run on an unmarked one hectare field or paved parking lot. Nine waypoints are scattered around a single start/finish point, and latitude and longitude of each of these targets is given to the participants. Construction barrels and other construction barriers are also located in the field so the vehicles cannot reach all waypoints by following straight lines without encountering an obstacle.

Teams placing in the competitions are awarded with individual point values for a grand award for the team

that represents best overall performance. For each competition, points will be awarded to each team, placing first, second, or third. The team with the most points at the end of the competition wins the $10,000 grand award. Below is a breakdown of the points:

	First	Second	Third
Autonomous Challenge	15 points	10 points	5 points
Navigation Challenge	10 points	8 points	6 points
Design Competition	10 points	8 points	6 points

Table 1: Grand Award point distribution.

Safety is a prime concern; vehicles that are judged to be unsafe are not allowed to compete. Therefore, participating vehicles must conform to specific safety regulations. They must conform to safety requirements that include the following criteria, speed limits, E-Stop (manual and a wireless remote) and indemnification agreements.

Figure 6: Brigham Young University – Urckbot, crossing the simulated asphalt.

TEAM TECHNOLOGIES

All of the vehicles entered into the IGVC are unique and different in design. Though most of the vehicles entered in the competition can be broken down into three main subsystems, mechanical, electrical and software. Fabrication of such a vehicle requires engineering knowledge from various disciplines. The most well rounded teams will employ engineers from several different fields to handle the needs of the project scope of work. Some teams even employ business and marketing students to help them make contact with industry and the military for both financial backing and durable goods needed for the project.

Mechanical subsystem teams are typically responsible for the chassis, propulsion system and body. The chassis designs for the robots are only limited by the design team's imagination and manufacturing capability.

Some teams build small inexpensive robots which are designed solely for the competition itself, entering multiple robots to increase the number of computer algorithms available to challenge the courses. Other teams build elaborate mechanical designs which are robust enough to be used for multiple robotic competitions. Regardless of which design philosophy a team uses, it is important to document the entire build process as the robot is built. Documentation can greatly improve reports required for the design competition.

Figure 7: University of Detroit Mercy – Warrior, ready for the rain on the Autonomous Challenge.

Before building the robot chassis a team must decide what their strategy for completing courses will be. The object of the autonomous challenge is to navigate obstacles on a curved course, over ramps, and through sand. Therefore, the vehicle requires the mobility to steer around obstacles, and the power to carry a 20lb payload over ramps. The Navigation Challenge only requires the robot to get from point a to point b as quickly as possible, without going over the 5mph speed limit. For obstacle avoidance on the Autonomous Challenge course a team can choose from steering controls such as Ackermann, differential, articulation, and omni directional steering. All steering strategies have been tried in past IGVC competitions with success limited only by the robustness of the chassis. A properly designed Ackermann or articulating robot can navigate obstacles as well as omni directional and differential steering robots. A team should choose whichever steering strategy they feel will best complement the robot's software control.

After choosing a basic steering design the team should consider how they will store and convert energy on their vehicle. Typically the robots are battery powered electric drive. However, there are examples of internal combustion engines powering in the past. So long as the design of the robot is structurally sound and energy transmission complies with relevant industry standards, a team can derive their power from batteries, fuel, or fuel cells. Teams should investigate the safe handling practices of each type of energy storage before choosing their power source. Also, a team should

research the logistics of their energy source, to make sure it is the best source for their design. For example, gasoline has a high energy density, but converting the energy into rotational and electrical power typically requires more equipment which may mitigate weight savings. Another example, lead acid batteries have a very low energy density, but they are less expensive and easier to maintain than lithium ion batteries.

Current platforms must be able to maneuver through several different types of terrain. The majority of the Autonomous Challenge course and possibly the entire Navigation Challenge course is freshly cut grass. There are parts of the Autonomous Challenge course which consist of sand, wood or tarmac. The terrain may also be wet and muddy. Differential tracked vehicles should be designed to have enough traction to propel them forward, while having enough slippage to control the direction of the vehicle's under steer. All platforms must have enough power to carry itself and the 20lb payload across the terrain gradients up to 15%. It is important to design the vehicle to carry extra power because a team cannot replace batteries or refuel once they start a performance event.

Braking is sometimes mechanical, but often results simply when power to the motors is cut off, and/or the very high gear ratios are used between motors and wheels. Suspension systems vary widely from sophisticated shock absorber/spring assemblies to solid mounting. Computers and electronic components are often soft-mounted. Majority of the vehicles are electric powered, but some have also been powered by internal combustion engines and hydraulic drive. Most vehicles have wheels, either three or four, but some have had two wheels or tracks similar to an army tank. Bodies are sometimes made of composite materials in very stylish, artistic, and creative forms, while others have no body covering at all and look like rolling laboratories.

Figure 8: Virginia Tech - Johnny 5, maneuvering the simulated sand on the Autonomous Challenge.

Electrical subsystem teams are generally responsible for most of the components on the vehicle, such as

batteries, computers, sensors, cameras and actuators. A typical vision system consists of a one or several color video or still cameras positioned on top of the vehicle that have to be interfaced with a computer. Frequently used sensors include SICK laser range finders, digital compasses, differential global position systems (DGPS), diffuse sensors, non-contact optical sensors and proximity sensors. Controllers are used for the motors, speed and actuators for steering and suspension. Most vehicles have several computers, though not always are they onboard, they are used for programming and vehicle diagnostics and are connected via hard wire or through a wireless local area network (LAN) connection.

Figure 9: University of Michigan-Dearborn - RoadRunner, crossing the ramp on the Practice Course.

Software teams are responsible for writing the software that controls all of the individual mechanical and electrical devices on the vehicle. Several different languages are used to write the code for the vehicles including C, C++, Visual Basic, LabVIEW and Java. Some teams are even making their vehicles compliant with the Joint Architecture for Unmanned Systems (JAUS); this is significant because JAUS is emerging as the DoD standard for all unmanned systems. The purpose of JAUS is interoperability between various unmanned systems and subsystems for both commercial and military applications, and is currently part of the Operational Requirement Document (ORD) for the Future Combat System (FCS).

Most teams use a closed-loop system for controlling their vehicles. A computer and controller feed information to motor controllers, which send electrical or mechanical energy to power the motors. This moves the vehicle, which is observed by encoders which can measure either the motors movement to determine where and how far the vehicle moved, or can measure the environment to determine how far it has traveled. These encoders then send that data back to the computer which uses it, among other data in determining what to do next.

A typical example of a vehicle's software system can often be broken down into main sub systems; for example main navigation algorithm, lane following algorithm, obstacle avoidance algorithm and waypoint algorithm. The main sub systems will take data from the other algorithms and use it to plan its path using 3D mapping to determine go and no go areas to choose an ideal case where there are no uncertainties. Using tools, such as differential equations and Extended Kalman Filter algorithms to determine the best path in light of the data and uncertainties in the situation.

Figure 10: École de technologie supérieure - Mentis II, fine-tuning their vehicle in the team tent.

Many robots used both video camera, single or stereo cameras and laser range data to create these 3D maps of the area. The laser range finders are often mounted less than a foot above the ground, looking parallel to the ground. The video cameras however, are often mounted several feet above the ground, looking downward at a 45 degree angle. This presented a problem to the teams, requiring them to determine how to integrate both sensors into the map and still utilize the sensors' capabilities. One way to do this was to convert the video data into laser range data format, and place it on the semicircle map created by the laser range finder.

The laser range finder map is converted into a form of x-y coordinates, which are then used to plan the path of the vehicle, looking forward at future movements and plotting its course on this 3D map. To do this, decision-making algorithms try to find a path to the end of their sensor range. If they cannot do this, they find the best possible path at a closer range, where new sensor data may generate new paths. Otherwise, like human drivers, the vehicles will back up and try another path.

Teams often incorporated a lane-continuation algorithm into their controllers, so that if a lane on either edge of the path disappeared for a distance, it would "extend" that line and maintain its course within that line as if it were still observed. Several teams are now using a systems engineering team to link all the subsystems together and make sure that all the pieces fit together. If systems are conflicting their responsibility is to

determine what is causing the problem. Then they can address the problem by either eliminating unnecessary equipment or software, or they can determine a new unique solution to solve the problem. The engineering challenge is to successfully build, integrate, test, tune and control the vehicle to meet the competition challenges within the time and resource constraints.

THE 2005 COMPETITION

The 13th Intelligent Ground Vehicle Competition was held on June 11-13, 2005 at Grand Traverse Resort and Spa, in Traverse City, Michigan. This year drew the highest number of teams registering, 37. Additionally, this year also had the most teams ever to appear at the competition, 30. Throughout the practice and qualification weekend, additional hardware and computer realities eliminated nine more participants for a total of 21 competing teams in the performance events.

An IGVC original event, the Autonomous Challenge requires the robots to drive a grass course, performing line-following and obstacle avoidance while driving over a ramp, through a sand pit, avoiding simulated potholes and keeping between dashed line markings. Virginia Tech's Gemini finished first receiving grand award money and completing the whole course in two minutes and ten seconds. Virginia Tech's Johnny 5 came in a very close second place, by completing the course in two minutes and eleven seconds for $1,500 in award money. Third place went to the Virginia Tech's Polaris, completing the course and received $1,000 in award money; Bluefield State College's Anassa also completed the course placing fourth and receiving $750 in award money.

Figure 11: United States Military Academy - Black MAGIC, getting ready for the Qualification Course.

The Design Competition component of the IGVC has been sponsored by the Society of Automotive Engineers (SAE) for 11 of the 13 years the competition has been held. Judges for this competition are chosen to reflect commercial and military applications of intelligent vehicles. Two weeks prior to the IGVC, all 30 teams

sent their technical papers to the 2005 judges for review. The teams were then randomly split into either Design Group A or Design Group B. During the competition each Design Group presented their design to a different group of independent judging panels. Each panel selected their top three teams and those teams represented their design presentation to the other panel of judges. Then both judging panels merge to score the top six finalists to determine a winner. The presentations and technical papers were evaluated and scored. Virginia Tech Gemini's design won first place and received grand award money, Virginia Tech's Polaris took second place and $1,000 in award money and third place and $500 in award money went to University of Central Florida's Calculon. Virginia Tech's Johnny 5, United States Military Academy's Black MAGIC and University of Central Florida's RDB3K were the other three finalists placing fourth, fifth and sixth respectively.

The Navigation Challenge for the fourth year demonstrated agile maneuvers based on navigating between a set of nine different GPS waypoints. The challenge was enhanced by deliberately setting obstacles between the waypoints. Teams had to optimize their routing while integrating machine vision to avoid the obstacles. Virginia Tech's Gemini finished first receiving grand award money and completing all nine waypoints in one minute and fifty-nine seconds. Virginia Tech's Polaris came in second place, by completing the course and receiving $1,000 in award money. Third place went to the Virginia Tech's Johnny 5, completing the course and received $500 in award money; Trinity College's ALVIN VI also completed the course placing fourth and receiving $350 in award money.

Figure 12: Bluefield State College's Anassa, navigating obstacles on the Autonomous Challenge course.

CONCLUSION

The Intelligent Ground Vehicle Competition made remarkable strides in the past 13 years. Hundreds of students from dozens of universities in several different countries have excelled in the application of cutting-edge technologies in engineering and computer science that have direct application in transportation, military, manufacturing, agriculture, recreation, space exploration, and many other fields. They have utilized professional design procedures and performed hands-on fabrication and testing. At the same time they have learned to work in teams and to understand the full product realization process. They have been creative and have at times demonstrated system and technology brilliance. The students are ready for full careers in the Intelligent Transportation Systems (ITS) engineering community. The IGVC is currently preparing for its 14th competition on June 10-12, 2006 at Selfridge Air National Guard Base in Harrison Township, Michigan. Visit the IGVC website at www.igvc.org for more information.

Figure 13: Virginia Tech - Polaris, being measured on the Qualification Course.

ACKNOWLEDGMENTS

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CONTACT

Bernard L. Theisen earned his M.S. in mechanical engineering from Oakland University and is currently on the Autonomous Navigation Team at the U.S. Army Tank Automotive Research, Development and Engineering Center in Warren, MI. He is a member of Theta Tau Professional Engineering Fraternity, AUVSI, ASME, SME, ESD and SAE. E-mail: theisenb@tacom.army.mil

ADDITIONAL SOURCES

Complete rules and other information about the IGVC can be obtained from the website www.igvc.org or by contacting Renee at (586) 574-8750 or rnlane@oakland.edu.

The 14th Annual Intelligent Ground Vehicle Competition will be held at Selfridge Air National Guard Base in Harrison Township, Michigan on June 10-12, 2006. It will be held in conjunction with the 6th Annual Intelligent Vehicle Systems Symposium & Exhibition at Grand Traverse Resort and Spa in Traverse City, Michigan on June 13-15, 2006.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

IGVC: Intelligent Ground Vehicle Competition

Figure 14: University of Cincinnati – BearCat III, maneuvering the Navigation Challenge Course.

APPENDIX

AUTONOMUS CHALLENGE RESULTS

The Autonomous Challenge Course has a total distance of 500 feet, which would be a perfect score. If more than one team receives a perfect score, placing will be determined by the fastest time to complete the entire 500 feet. Listed below is the placing of all seventeen teams that competed in this event.

First place Gemini from Virginia Polytechnic Institute and State University, 500 feet in 2 minutes and 10 seconds; second place Johnny 5 from Virginia Polytechnic Institute and State University, 500 feet in 2 minutes and 11 seconds; third place Polaris from Virginia Polytechnic Institute and State University, 500 feet in 3 minutes and 30 seconds; fourth place Anassa from Bluefield State College, 500 feet in 3 minutes and 55 seconds; fifth place Urckbot from Brigham Young University, 351 feet in 4 minutes and 22 seconds; sixth place Warrior from University of Detroit Mercy, 276 feet in 3 minutes and 33 seconds; seventh place RoadRunner from University of Michigan - Dearborn, 250 feet 3 minutes and 27 seconds; eighth place G2 from University of Minnesota, 237 feet in 4 minutes and 36 seconds; ninth place Yellow Jacket from Cedarville University, 236 feet and 6 inches in 5 minutes; tenth place Think-Tank from Lawrence Technological University, 232 feet in 4 minutes and 9 seconds; eleventh place ALVIN VI from Trinity College, 219 feet in 4 minutes and 42 seconds; twelfth place Calculon from University of Central Florida, 158 feet in 5 minutes; thirteenth place Whitespace from University of Wisconsin-Madison, 154 feet in 5 minutes; fourteenth place amigo2005 from Hosei University, 136 feet in 1 minute and 48 seconds; fifteenth place Adam from Bob Jones University, 122 feet 2 minutes in 31 seconds; sixteenth place Bearcat Cub from University of Cincinnati, 95 feet in 5 minutes; seventeenth place SMART 2005 from University of Michigan - Dearborn, 88 feet in 1 minutes and 22 seconds; eighteenth place Bearcat III from University of Cincinnati, 83 feet in 3 minutes and 10 seconds; nineteenth place Proteus from Oakland University, 56 feet and 4 inches in 48 seconds; twentieth place Should Be Trivial… from University of Maryland - Baltimore County, 2 feet in 33 seconds; twenty-first place MARVIN from University of Minnesota - Duluth, -3 feet in 43 seconds.

DESIGN COMPETITION RESULTS

The Design Competition is based on a SAE paper and has a total possible score of 800, which would be a perfect score. The teams were randomly split into either Design Group A or Design Group B. During the competition each Design Group presented their design to a different group of independent judging panels. Each panel selected their top three teams and those teams represented their design presentation to the other panel of judges. Then both judging panels merge to score the top six finalists to determine a winner. Listed below is the placing of all thirty teams that competed in this event.

For the Finalists: First place Gemini from Virginia Polytechnic Institute and State University with 712.25 points; second place Polaris from Virginia Polytechnic Institute and State University with 708.75 points; third place Calculon from University of Central Florida with 708.25 points; fourth place Johnny 5 from Virginia Polytechnic Institute and State University with 707.25 points; fifth place Black MAGIC from United States Military Academy with 683.50 points; sixth place RDB3K from University of Central Florida with 666.00 points.

Figure 15: Lawrence Technological University – Think-Tank, on the Autonomous Challenge Course.

For Design Group A: First place Calculon from University of Central Florida with 740.50 points; second place Black MAGIC from United States Military Academy with 735.50 points; third place Gemini from Virginia Polytechnic Institute and State University with 732.00 points; fourth place Anassa from Bluefield State College with 727.50 points; fifth place amigo2005 from Hosei University with 726.00 points; sixth place Whitespace from University of Wisconsin-Madison with 724.00 points; seventh place Urckbot from Brigham Young University with 699.00 points; eighth place Adam from Bob Jones University with 695.00 points; ninth place Yellow Jacket from Cedarville University with 694.00 points; tenth place G2 from University of Minnesota with 683.50 points; eleventh place Bearcat Cub from University of Cincinnati with 680.00 points; twelfth place MARVIN from University of Minnesota - Duluth with 662.50 points; thirteenth place Should Be Trivial… from University of Maryland - Baltimore County with 638.50 points; fourteenth place Bearcat III from University of Cincinnati with 628.50 points; fifteenth place RoadRunner from University of Michigan - Dearborn with 622.50 points; sixteenth place SMART 2005 from University of Michigan - Dearborn with 622.50 points; seventeenth place GCAT 2005 from University of Michigan - Dearborn with 612.50 points. For Design Group B: First place Polaris from Virginia Polytechnic Institute and State University with 708.00 points; second place Johnny 5 from Virginia Polytechnic Institute and State University with 699.00 points; third place RDB3K from University of Central Florida with 638.00 points; fourth place TIE rho-bot from University of Missouri - Rolla with 615.50 points; fourth place TIE Think-Tank

from Lawrence Technological University with 615.50 points; sixth place Mentis II from École de technologie supérieure with 609.50 points; seventh place ALVIN VI from Trinity College with 609.00 points; eighth place Hephaestus from University of Detroit Mercy with 589.50 points; ninth place Warrior from University of Detroit Mercy with 587.50 points; tenth place Bulldog I from Kettering University with 586.50 points; eleventh place NJAV I from The College of New Jersey with 561.00 points; twelfth place Proteus from Oakland University with 553.00 points; thirteenth place MCP from University of Massachusetts - Lowell with 263.00 points.

NAVIGATION CHALLENGE RESULTS

The Navigation Challenge Course has a total of 9 waypoints, which would be a perfect score. If more than one team receives a perfect score, placing will be determined by the fastest time to complete all 9 waypoints.   Listed below is the placing of all fifteen teams that competed in this event.

First place Gemini from Virginia Polytechnic Institute and State University, 9 waypoints in 1 minutes and 59 seconds; second place Polaris from Virginia Polytechnic Institute and State University, 9 waypoints in 2 minutes and 42 seconds; third place Johnny 5 from Virginia Polytechnic Institute and State University, 9 waypoints in 2 minutes and 50 seconds; fourth place ALVIN VI from Trinity College, 9 waypoints in 4 minutes and 24 seconds; fifth place Bearcat Cub from University of Cincinnati, 7 waypoints in 3 minutes 30 second; sixth place Adam from Bob Jones University, 7 waypoints in 5 minute and 42 seconds; seventh place amigo2005 from Hosei University, 6 waypoints in 2 minutes; eighth place Calculon from University of Central Florida, 6 waypoints in 2 minutes and 37 seconds; ninth place Think-Tank from Lawrence Technological University, 4 waypoints in 3 minutes and 50 seconds; tenth place Bearcat III from University of Cincinnati, 4 waypoints in 5 minutes and 25 seconds; eleventh place G2 from University of Minnesota, 3 waypoints in 1 minutes and 32 seconds; twelfth place Urckbot from Brigham Young University, 2 waypoints in 41 seconds; thirteenth place Anassa from Bluefield State College, 2 waypoints in 1minute and 8 seconds; fourteenth place GCAT 2005 from University of Michigan-Dearborn, 1 waypoint in 50 seconds; fifteenth place SMART 2005 from University of Michigan-Dearborn, 1 waypoint in 57 seconds.

Figure 16: Bob Jones University - Adam, on the Autonomous Challenge Course.